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(54) **INTEGRATED CIRCUIT INCLUDING A POWER TRANSISTOR AND AN AUXILIARY TRANSISTOR**

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USPC **257/467**

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USPC 257/467–470
See application file for complete search history.

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(57) **ABSTRACT**

In one embodiment of an integrated circuit, the integrated circuit includes a power transistor with a power control terminal, a first power load terminal and a second power load terminal. The integrated circuit further includes an auxiliary transistor with an auxiliary control terminal, a first auxiliary load terminal and a second auxiliary load terminal. The first auxiliary load terminal is electrically coupled to the power control terminal. The integrated circuit further includes a capacitor with a first capacitor electrode, a second capacitor electrode and a capacitor dielectric layer. The capacitor dielectric layer includes at least one of a ferroelectric material and a paraelectric material. The first capacitor electrode is electrically coupled to the auxiliary control terminal.

23 Claims, 3 Drawing Sheets

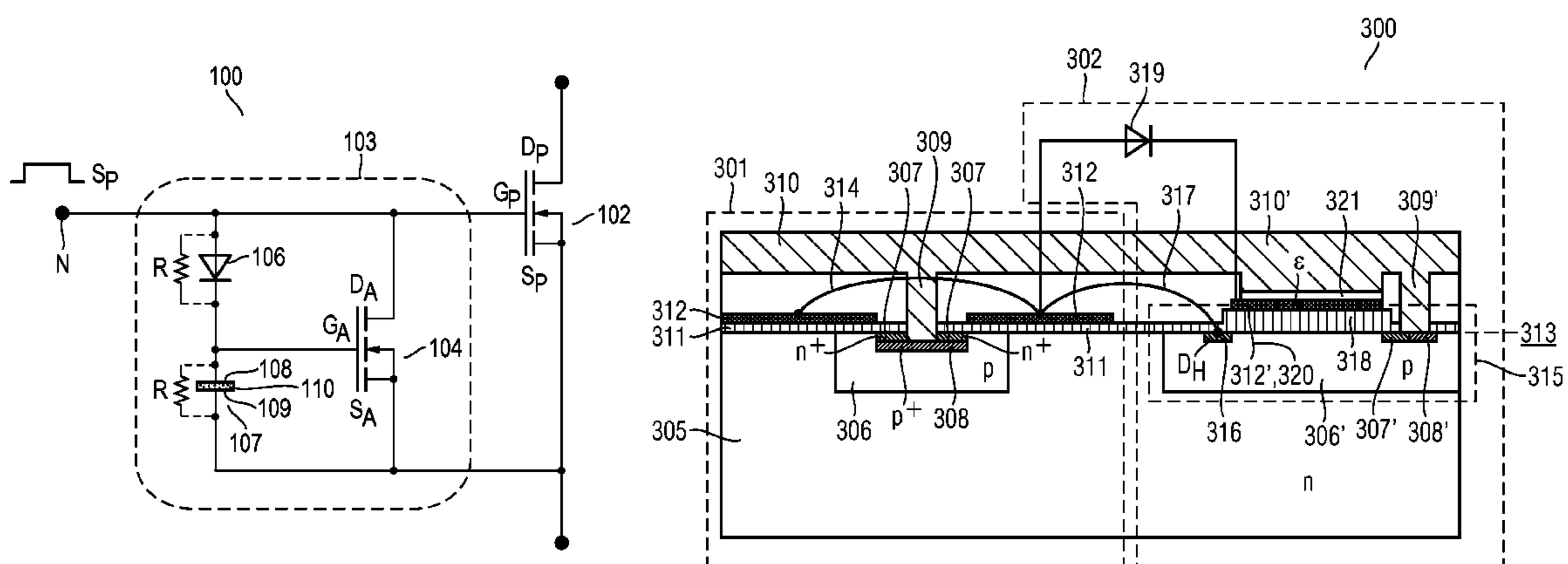


FIG 1

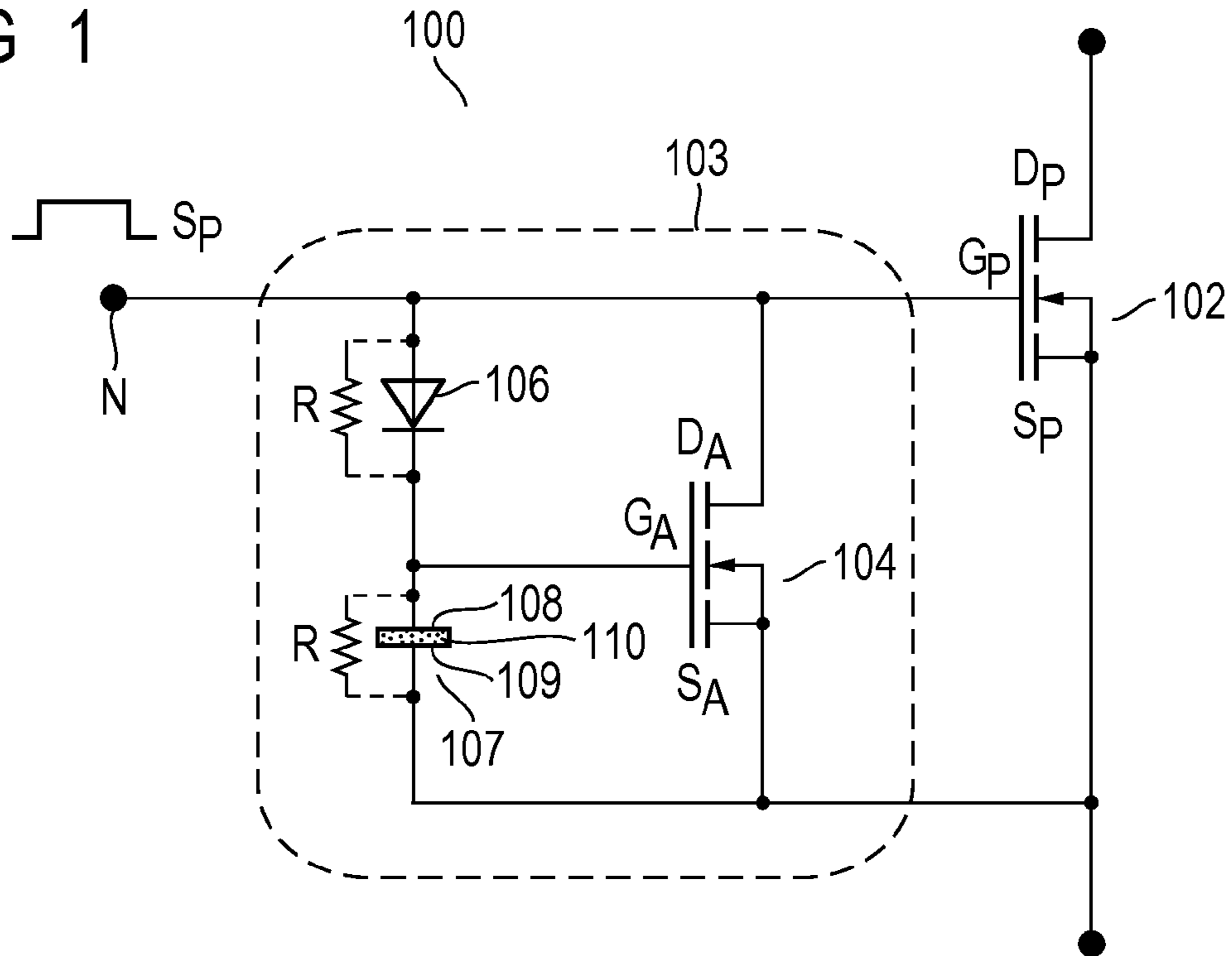


FIG 2

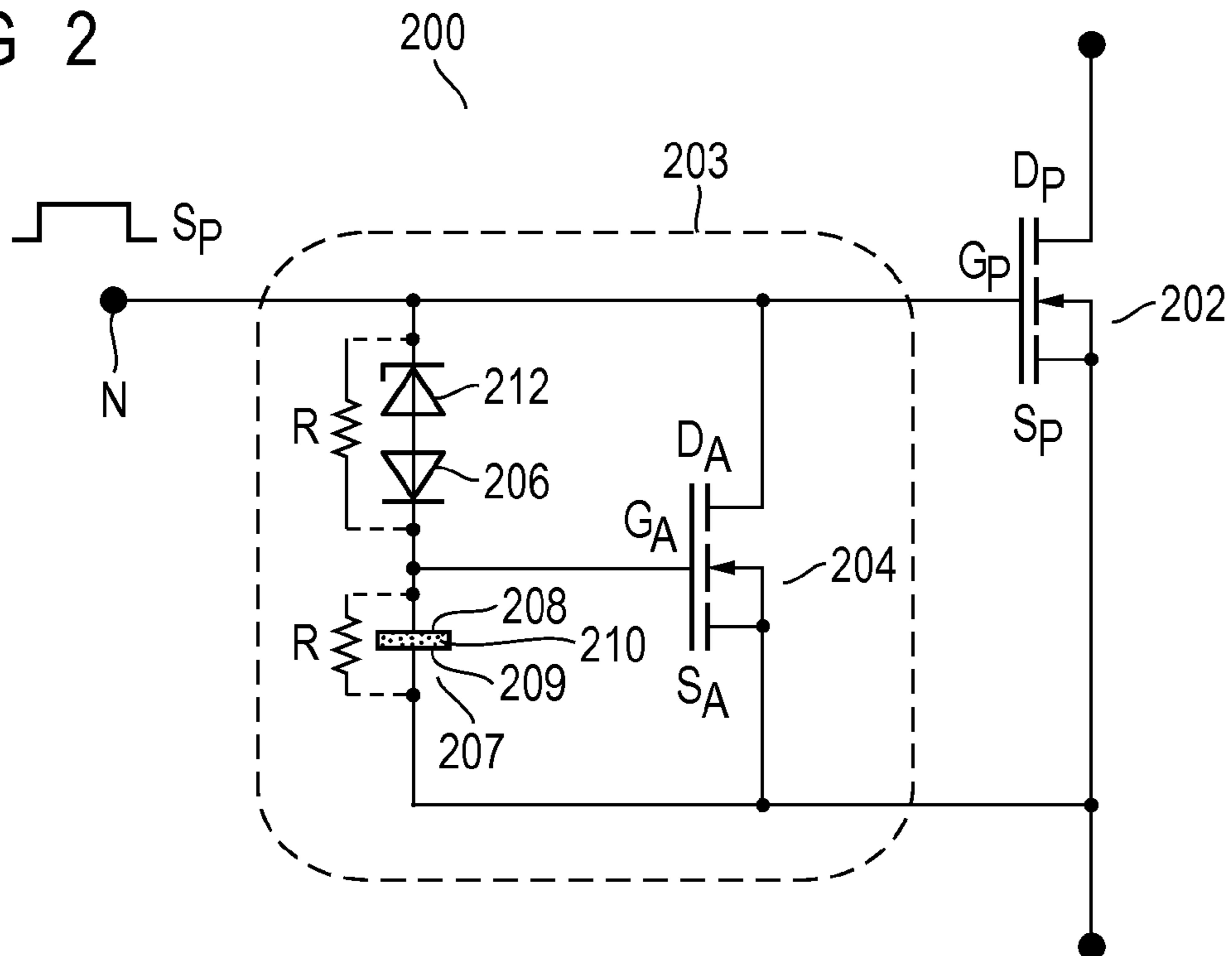


FIG 4

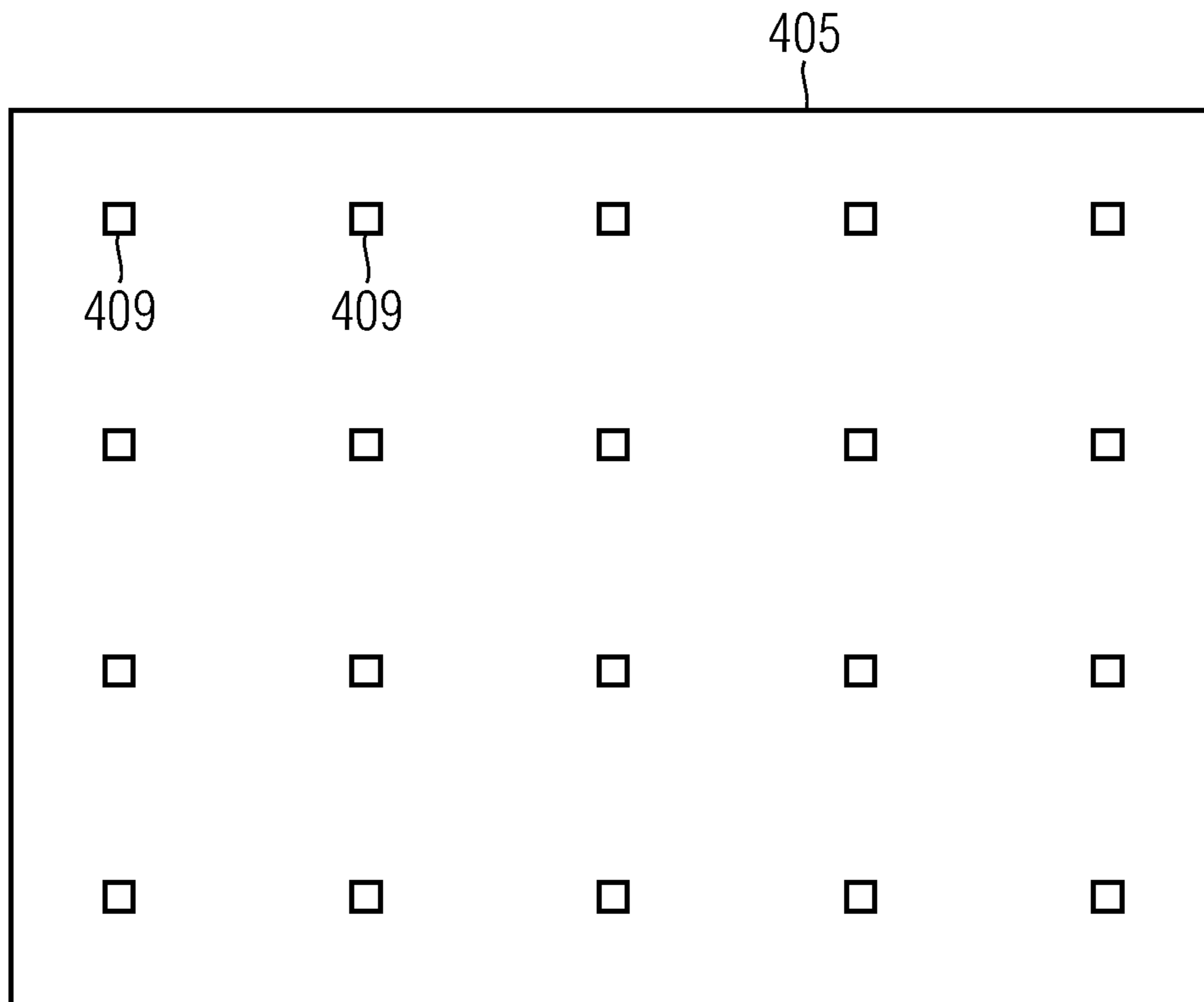
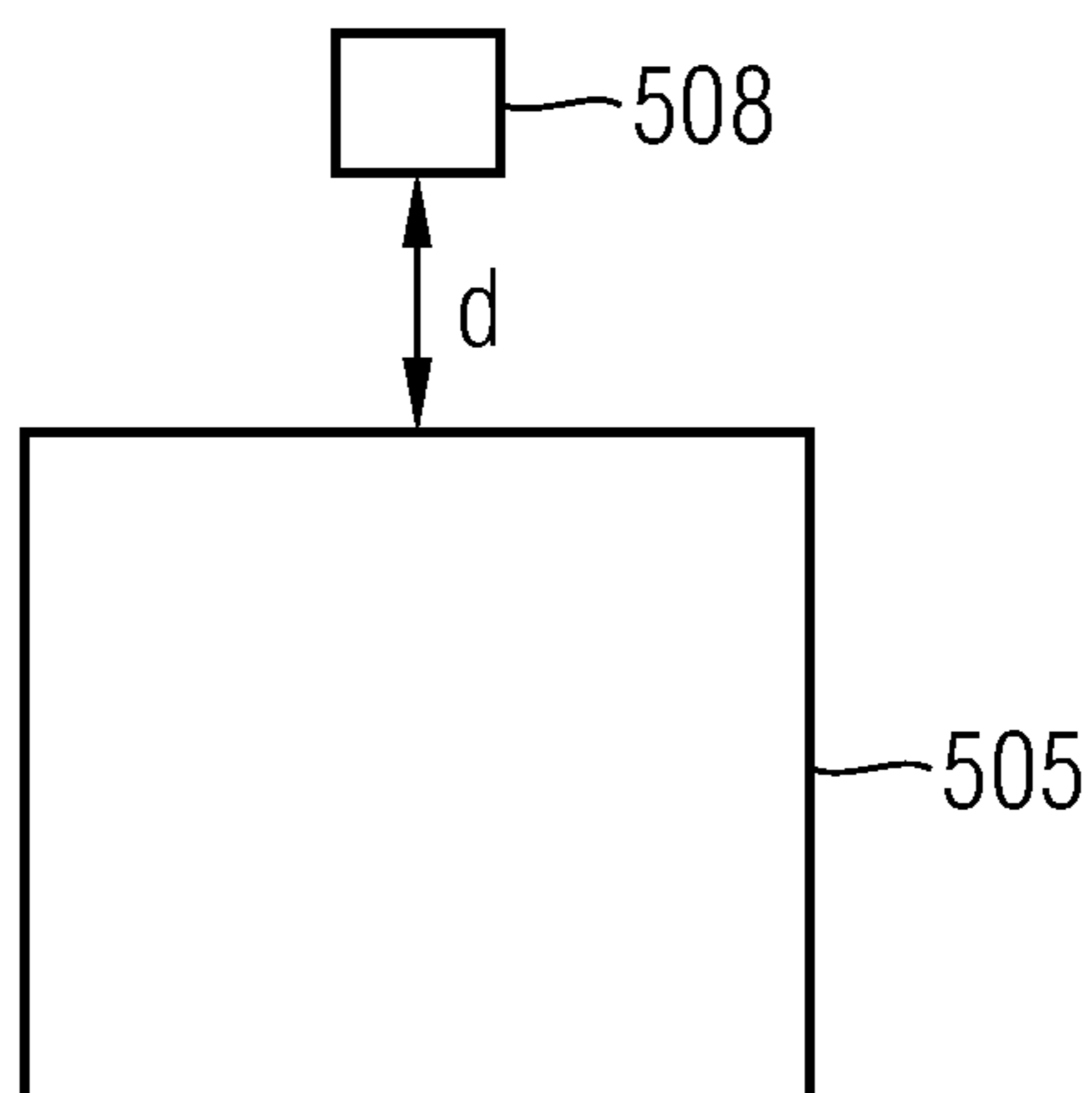


FIG 5



1

**INTEGRATED CIRCUIT INCLUDING A
POWER TRANSISTOR AND AN AUXILIARY
TRANSISTOR**

BACKGROUND

During operation, semiconductor components such as switches in power supplies and power converters are heated due to power dissipation within these components.

If semiconductor components are operated below the so-called stable-temperature point, current filamentation may occur and lead to a destruction of the semiconductor components.

As a counter measure to excessive heating and current filamentation, electrical parameters such as forward current, dI/dt , dU/dt , temperature etc. are generally limited appropriately and kept within a safe operation area range (SOA range) during operation. Limitation of the operation range to a safe operation area, however, restricts further improvements of the characteristics of the semiconductor components.

Thus, it is desirable to improve protection of semiconductor components against excessive heating and current filamentation.

SUMMARY

According to one embodiment of an integrated circuit, the integrated circuit includes a power transistor with a power control terminal, a first power load terminal and a second power load terminal. The integrated circuit further includes an auxiliary transistor with an auxiliary control terminal, a first auxiliary load terminal and a second auxiliary load terminal. The first auxiliary load terminal is electrically coupled to the power control terminal. The integrated circuit further includes a capacitor with a first capacitor electrode, a second capacitor electrode and a capacitor dielectric layer. The capacitor dielectric layer includes at least one of a ferroelectric material and a paraelectric material. The first capacitor electrode is electrically coupled to the auxiliary control terminal.

Those skilled in the art will recognize additional features and advantages upon reading the following detailed description, and on viewing the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide a further understanding of the present invention and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the present invention and together with the description serve to explain principles of the invention. Other embodiments of the present invention and many of the intended advantages of the present invention will be readily appreciated as they become better understood by reference to the following detailed description. The elements of the drawings are not necessarily to scale relative to each other. Like reference numerals designate corresponding similar parts. The features of the various illustrated embodiments can be combined unless they exclude each other.

Embodiments are depicted in the drawings and are detailed in the description which follows.

FIG. 1 is a schematic illustration of a part of an integrated circuit including a power transistor with a power control terminal that is electrically coupled to a protection circuit including a diode and a capacitor.

FIG. 2 is a schematic illustration of a part of an integrated circuit including a power transistor with a power control

2

terminal that is electrically coupled to a protection circuit including two diodes and a capacitor.

FIG. 3 is a schematic illustration of a vertical cross section through a part of a power transistor cell array including an auxiliary transistor and a capacitor electrically coupled to an auxiliary control terminal of the auxiliary transistor.

FIG. 4 is a schematic top view of one layout of a power transistor cell array and a protection circuit having protection circuit parts spread evenly over the power transistor cell array.

FIG. 5 is a schematic top view of one layout of a power transistor cell array and a protection circuit having a lateral distance to the power transistor cell array.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. In this regard, directional terminology, such as “top”, “bottom”, “front”, “back”, “leading”, “trailing”, “over”, “above”, “below”, etc., is used with reference to the orientation of the Figure(s) being described. Because components of the embodiments can be positioned in a number of different orientations, the directional terminology is used for purposes of illustration and is in no way limiting. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present invention. For example, features illustrated or described as part of one embodiment can be used on or in conjunction with other embodiments to yield yet a further embodiment. It is intended that the present invention includes such modifications and variations. The examples are described using specific language which should not be construed as limiting the scope of the appending claims. The drawings are not scaled and are for illustrative purposes only. For clarity, the same elements or manufacturing processes have been designated by the same references in the different drawings if not stated otherwise.

The terms “lateral” and “horizontal” as used in this specification intends to describe an orientation parallel to a first surface of a semiconductor substrate or semiconductor body. This can be for instance the surface of a wafer or a die.

The term “vertical” as used in this specification intends to describe an orientation which is arranged perpendicular to the first surface of the semiconductor substrate or semiconductor body.

As employed in this specification, the terms “coupled” and/or “electrically coupled” are not meant to mean that the elements must be directly coupled together—intervening elements may be provided between the “coupled” or “electrically coupled” elements. The term “electrically connected” intends to describe a low-ohmic electric connection between the elements electrically connected together, e.g. a connection via a metal and/or highly doped semiconductor.

In this specification, n-doped may refer to a first conductivity type while p-doped is referred to a second conductivity type. It goes without saying that the semiconductor devices can be formed with opposite doping relations so that the first conductivity type can be p-doped and the second conductivity type can be n-doped. Furthermore, some Figures illustrate relative doping concentrations by indicating “-” or “+” next to the doping type. For example, “n⁻” means a doping concentration which is less than the doping concentration of an “n”-doping region while an “n⁺”-doping region has a larger doping concentration than the “n”-doping region. Indicating the relative doping concentration does not, however, mean that doping regions of the same relative doping concentration

have the same absolute doping concentration unless otherwise stated. For example, two different n⁺-doped regions can have different absolute doping concentrations. The same applies, for example, to an n⁺-doped and a p⁺-doped region.

Specific embodiments described in this specification pertain to, without being limited thereto, power semiconductor devices which are controlled by field-effect and particularly to unipolar devices such as MOSFETs.

The term “field-effect” as used in this specification intends to describe the electric field mediated formation of an “inversion channel” and/or control of conductivity and/or shape of the inversion channel in a semiconductor channel region.

In the context of the present specification, the term “field-effect structure” intends to describe a structure which is formed in a semiconductor substrate or semiconductor body or semiconductor device and has a gate electrode which is insulated at least from the body region by a dielectric region or dielectric layer. Examples of dielectric materials for forming a dielectric region or dielectric layer between the gate electrode and the body region include, without being limited thereto, silicon oxide (SiO₂), silicon nitride (Si₃N₄), silicon oxynitride (SiO_xN_y), zirconium oxide (ZrO₂), tantalum oxide (Ta₂O₅), titanium oxide (TiO₂) and hafnium oxide (HfO₂) or stacks of these materials.

Above a threshold voltage V_{th} between the gate electrode and the source electrode connected typically to the body region, an inversion channel is formed and/or controlled due to the field-effect in a channel region of the body region adjoining the dielectric region or dielectric layer. The threshold voltage V_{th} typically refers to the minimum gate voltage necessary for the onset of a unipolar current flow between the two semiconductor regions of the first conductivity type, which form the source and the drain of a transistor.

In the context of the present specification, the term “MOS” (metal-oxide-semiconductor) should be understood as including the more general term “MIS” (metal-insulator-semiconductor). For example, the term MOSFET (metal-oxide-semiconductor field-effect transistor) should be understood to include FETs having a gate insulator that is not an oxide or a gate material that is not a metal, i.e., the term MOSFET is used in the more general term meaning IGFET (insulated-gate field-effect transistor) and MISFET, respectively.

Further, terms such as “first”, “second”, and the like, are also used to describe various elements, regions, sections, etc. and are also not intended to be limiting. Like terms refer to like elements throughout the description.

As used herein, the terms “having”, “containing”, “including”, “comprising” and the like are open ended terms that indicate the presence of stated elements or features, but do not preclude additional elements or features. The articles “a”, “an” and “the” are intended to include the plural as well as the singular, unless the context clearly indicates otherwise.

FIG. 1 illustrates a part of a circuit diagram of an integrated circuit 100 according to an embodiment. The integrated circuit 100 includes an n-type MOSFET (NMOS) 102. The NMOS 102 includes a drain terminal D_P as a first load terminal, a source terminal S_P as a second load terminal and a gate terminal G_P as a power control terminal.

The integrated circuit 100 further includes an auxiliary NMOS 104. A drain terminal D_A of the auxiliary NMOS 104 constituting a first load terminal is electrically connected to the gate terminal G_P of the power NMOS 102. A source terminal S_A constituting a second load terminal of the auxiliary NMOS 104 is electrically connected to the source terminal S_P of the power transistor 102.

A serial connection of a diode 106 and a capacitor 107 is connected in parallel with the drain and source terminals D_A , S_A of the auxiliary NMOS 104. An anode of the diode 106 is electrically connected to both the drain terminal D_A of the auxiliary NMOS 104 and the gate terminal G_P of the power NMOS 102. The capacitor 107 includes a first capacitor electrode 108 electrically connected to both a cathode of the diode 106 and a control terminal G_A of the auxiliary NMOS 104, a second capacitor electrode 109 of the capacitor 107 is electrically connected to both the source terminal S_A of the auxiliary NMOS 104 and the source terminal S_P of the power NMOS 102. A capacitor dielectric layer 110 of the capacitor 107 includes at least one of a ferroelectric material and a paraelectric material. The capacitor dielectric layer 110 includes a relative dielectric constant ϵ_r , with a negative temperature coefficient. The capacitor dielectric layer 110 may include a ferroelectric material having a Curie point T_C of less than 300 K. According to an embodiment, the relative dielectric constant $\epsilon_r(T_1)$ of the capacitor dielectric layer 110 at a temperature $T_1=400$ K and the relative dielectric constant $\epsilon_r(T_2)$ of the capacitor dielectric layer 110 at the temperature $T_2=475$ K satisfies $\epsilon_r(T_2) \leq 0.75 \times \epsilon_r(T_1)$. According to another embodiment, the capacitor dielectric layer 110 includes a paraelectric material or a ferroelectric material comprising at least one of BaTiO₃, SrTiO₃, Ba_xSr_{1-x}TiO₃ and KTaO₃.

During operation of the integrated circuit 100, a gate signal S_P is supplied to the gate terminal G_P of the power NMOS 102 via a node N. When the power NMOS 102 is turned on via the gate signal S_P , the capacitor 107 is charged via the diode 106. By adjusting a threshold voltage of the auxiliary NMOS 104 above the threshold voltage of the power NMOS 102, the gate signal S_P turns on the power NMOS 102 while the auxiliary NMOS 104 remains turned off. The capacitor dielectric 110 may be thermally coupled to the power NMOS 102 by limiting a distance between the capacitor 107 and the transistor cell area of the power NMOS 102, e.g. by spreading sub capacitors of the capacitor 107 evenly over the cell area of the power NMOS 102.

When a temperature within the power NMOS 102 rises, e.g. due to a short circuit of the power NMOS 102, a temperature within the capacitor dielectric layer 110 also rises. Due to the negative temperature coefficient of the relative dielectric constant ϵ_r of the capacitor dielectric layer 110, the value of capacitance of the capacitor 107 decreases. Since the diode 106 prevents a discharge of the capacitor 107 via the node N, a voltage drop across the capacitor 107 increases. Hence, also the voltage drop between the gate terminal G_A and the source terminal S_A of the auxiliary NMOS 104 increases. When the voltage at the gate terminal G_A of the auxiliary NMOS 104 exceeds the threshold voltage of the auxiliary NMOS 104, the auxiliary NMOS 104 is turned on leading to a short circuit between the gate terminal G_P and the source terminal S_P of the power NMOS 102. As a consequence, the power NMOS 102 is turned off.

Thus, a protection circuit 103 including elements 104, 106, 107 allows to turn off the power NMOS 102 by making use of the decrease of the relative dielectric constant ϵ_r of the capacitor dielectric layer 110 when the temperature within the capacitor dielectric layer 110 increases due to heat diffusion from the power NMOS 102 thermally coupled to the capacitor 107. The power NMOS 102 may be turned off at a desired threshold temperature by appropriately adjusting parameters of the protection circuit 103 such as characteristics of the auxiliary transistor 104, e.g. threshold voltage, as well as characteristics of the capacitor 107, e.g. the relative dielectric constant ϵ_r .

According to one embodiment the threshold voltage of the auxiliary NMOS **104** exceeds the threshold voltage of the power NMOS **102** in a way, that at a typical operating gate voltage of the power NMOS **102** the leakage current of the auxiliary NMOS **104** is still low, which means that the threshold voltage of the auxiliary NMOS **104** is above the typical operating gate voltage of the power NMOS **102**. Since typically the power NMOS **102** has a threshold voltage in the range of approximately 0.8V to approximately 8V and is operated with typical gate voltages in the range of about 3.3V to about 20V, the threshold voltages of the auxiliary NMOS **104** are above 3.3V up to 20V. The auxiliary NMOS **104** may have a threshold voltage that is typically more than 50% higher than that of the power NMOS **102**.

According to one embodiment, a driver circuit supplying the gate signal S_P to the gate terminal G_P of the power NMOS **102** via the node N is configured to secure a time period Δt between a turning off of the power NMOS **102** due to the protection circuit **103** and a new turning on of the power NMOS **102**. The time period Δt may be chosen appropriately to account for a hysteresis of the capacitor dielectric layer **110** by securing a sufficient cooling down of the power NMOS **102** and the capacitor dielectric layer **110**.

According to one embodiment, a value of a dropping resistor R_d of the gate terminal G_P of the power NMOS **102** connected e.g. between terminal N in FIG. 1 and a driver circuit, i.e. a resistor used in series with the gate terminal G_P , is set in relation to the on-state resistance of the auxiliary NMOS **104** R_{aux} according to:

$$R_d < R_{aux} \cdot \left(\frac{V_{driver}}{V_{th,NMOS}} - 1 \right) \quad (\text{eq. 1})$$

where V_{driver} gives the no-load output voltage of the driver circuit connected to terminal N via the dropping resistor and $V_{th,NMOS}$ relates to the threshold voltage of the power NMOS **102**. By fulfilling equation 1 it is secured that the voltage at the gate G_P of the power NMOS **102** is low enough to turn off the power NMOS **102** when the auxiliary NMOS **104** is in conducting mode.

FIG. 2 illustrates a part of a circuit diagram of an integrated circuit **200** according to another embodiment. Similar to circuit elements **102**, **104**, **106**, **107** of the integrated circuit **100** illustrated in FIG. 1, the integrated circuit **200** includes a power NMOS **202** having a source terminal S_P , a drain terminal D_P and a gate terminal G_P , an auxiliary NMOS **204** having a source terminal S_A , a drain terminal D_A and a gate terminal G_A , a first diode **206** and a capacitor **207** including a first capacitor electrode **208**, a second capacitor electrode **209** and a capacitor dielectric layer **210**. The integrated circuit **200** differs from the integrated circuit **100** illustrated in FIG. 1 in that the protection circuit **203** further includes a second diode **212**. The first diode **206** and the second diode **212** are antiseri-ally connected diodes having their anodes interconnected. Thus, a cathode of the second diode **212** is electrically connected to both the drain terminal D_A of the auxiliary NMOS **204** and the gate terminal G_P of the power NMOS **202**.

The second diode **212** is operated in a reserve breakdown mode when the power NMOS **202** is turned on via a respective gate signal S_P supplied via node N. In this operation mode, a voltage at the gate terminal G_A of the auxiliary NMOS **204** is smaller than the voltage at the gate terminal G_P of the power NMOS **102** and a difference between these gate voltages equals the breakdown voltage of the second diode **212**. Similar to the embodiment of the integrated circuit **100**

illustrated in FIG. 1, also the protection circuit **203** turns the power NMOS **202** off in case that the temperature of the capacitor dielectric layer **210** exceeds a certain threshold temperature, or, in other words, the relative dielectric constant ϵ_r of the capacitor dielectric layer **210** falls below a certain threshold value. Assuming that voltages supplied to the gate terminal G_P of the power NMOS **202** in an on-state operation mode range within 10 V and 15 V, typical breakdown voltage of the second diode **212** range between 5 V and 8 V.

In the integrated circuit **200**, the fractional amount of the gate signal S_P supplied to the gate terminal G_A of the auxiliary NMOS **204** is smaller than the respective fractional amount of the gate signal S_P supplied to the gate terminal G_A of the auxiliary NMOS **104** of the integrated circuit **100** illustrated in FIG. 1. The embodiment illustrated in FIG. 2 is beneficial since the auxiliary NMOS **204** and the power NMOS **202** may include equal or similar threshold voltages. Gate dielectrics of the auxiliary NMOS **204** and the power NMOS **202** may be manufactured in a common process or with similar requirements on reliability of the gate dielectrics.

High-ohmic resistors (R) may be connected in parallel to the diode(s) and/or the capacitor illustrated in FIGS. 1 and 2. This allows to e.g. drain off a leakage current of the second diode **212** to the source terminal S_A of the auxiliary NMOS **204**, for example and also hinders a gate charge at the gate terminal G_A from being discharged too fast. Typical values for these resistors are above 1 k Ω more typically above 100 k Ω or above 1 M Ω . Such high-ohmic resistors (R) are shown connected with dashed lines in FIGS. 1 and 2 to indicate they are optional.

In the integrated circuits **100**, **200** illustrated in FIGS. 1 and 2, the power transistor is illustrated as an NMOS. According to other embodiments, the power transistor may be any of a p-type or n-type channel field effect transistor such as a MOSFET or an IGBT (insulated gate bipolar transistor). Likewise, also the auxiliary transistor illustrated as an NMOS in FIGS. 1 and 2 may also be formed as any of an n-type or p-type field effect transistor such as a MOSFET.

According to another embodiment which is not illustrated in the Figures, the gate terminal G_A of the auxiliary NMOS may be connected to another gate voltage, e.g. via a rectifying element. Using another drive voltage for the gate terminal G_A of the auxiliary NMOS may be helpful since the same process steps may be used to manufacture the auxiliary NMOS and the power NMOS and maintain different gate voltages related to the threshold voltage of power NMOS and auxiliary NMOS which in this case can be chosen in the same range.

FIG. 3 illustrates a schematic cross-section through a part of an integrated circuit **300** according to an embodiment. The integrated circuit **300** includes a monolithic integration of a power transistor and a protection circuit including an auxiliary transistor, a capacitor and a diode. These circuit elements are interconnected as illustrated in the schematic circuit diagram of FIG. 1. A part of the cell area of the power transistor is illustrated in area **301** of FIG. 3 and a part of the protection circuit is illustrated in area **302** of FIG. 3.

The integrated circuit **300** includes an n-doped semiconductor body **305** such as an n-doped semiconductor substrate, e.g. a substrate made of silicon (Si) or silicon-on-insulator (SOI) or also made of a wide bandgap material like e.g. SiC or GaN. In the area **301**, a part of a cell area of the power NMOS is illustrated. The power NMOS includes a p-doped body region **306** and n⁺-doped source regions **307**. A p⁺-doped body contact zone **308** and a contact **309**, e.g. a conductive plug or a conductive line, electrically couple the p-doped body region **306** to a conductive source layer **310**, e.g. a

source metallization. A gate dielectric **311** and a gate electrode **312** are arranged on a first side **313** of the n-doped semiconductor body **305**. A short-circuit between the gate electrodes **312** of different transistor cells is illustrated in FIG. **3** in a simplified manner by a wire **314**. The wire **314** may include one or a plurality of conductive layers or conductive lines formed by structuring one or a plurality of conductive layers in another part of the integrated circuit **300**, i.e. in a part not illustrated in the cross-section of FIG. **3**.

In the area **302** of the protection circuit, an auxiliary NMOS **315** includes a p-doped body region **306'**, n⁺-doped source region **307'** and a p⁺-doped body contact zone **308'**. The p-doped body region **306'** is electrically coupled to the conductive source layer **310** via the p⁺-doped body contact zone **308'** and a contact **309'**. Likewise, the source region **307'** is electrically coupled to the conductive source layer **310** via the contact **309'**. The auxiliary NMOS **315** further includes an n⁺-doped drain region **316** that is electrically coupled to the gate **312** of the power NMOS. The electrical connection is illustrated in a simplified manner by a wire **317** that may include one or a plurality of conductive layers or conductive lines formed by structuring one or a plurality of conductive layers.

On the n-doped semiconductor body **305** at the first side **313**, a gate dielectric **318** and a gate electrode **312'** are arranged. A thickness of the gate dielectric **318** of the auxiliary NMOS **315** is larger than the thickness of the gate dielectric **311** of the power NMOS in the area **301** assuming that a material of the gate dielectrics **311**, **318** is the same. According to other embodiments, the thickness of the gate dielectric **318** equals or is smaller than the thickness of the gate dielectric **311** provided that the threshold voltage of the auxiliary NMOS **315** is larger than the threshold voltage of the power NMOS, e.g. by choosing different materials for the dielectrics **311**, **318** and/or by choosing an appropriate level of doping for the body region **306'**. Thus, a threshold voltage of the auxiliary NMOS **315** is set higher than the threshold voltage of the power NMOS in the area **301**. The gate electrode **312'** of the power NMOS is electrically coupled to the gate electrode **312'** of the auxiliary NMOS **315** via a diode which is illustrated in the cross-sectional view of FIG. **3** in a simplified manner by a diode symbol denoted by reference number **319**.

The gate electrode **312'** further constitutes a first capacitor electrode **320** of a capacitor further including a capacitor dielectric layer **321** and a second capacitor electrode **310'** formed in the same layer as the conductive source layer **310**.

The capacitor dielectric layer **321** may be formed as described with regard to the capacitor dielectric layer **110** illustrated in FIG. **1**.

In the integrated circuit **300**, the p-doped body regions **306**, **306'** may be simultaneously formed, for example. Likewise, the n⁺-doped source regions **307**, **307'** and the n⁺-doped drain region **316** may be simultaneously formed. Also the p⁺-type body contact zones **308**, **308'** may be simultaneously formed. Also the gate electrodes **312**, **312'** may be simultaneously formed, for example. Hence, these elements, e.g. regions **306**, **306'**, may be formed by patterning a same layer or a same layer stack. A drain contact of the power NMOS in an area **301** may be arranged at a rear side of the n-doped semiconductor body **305** opposite the first side **313**, for example (not illustrated in FIG. **3**).

FIG. **4** is a schematic illustration of a top view on one layout of an integrated circuit according to an embodiment. The integrated circuit includes a transistor cell area **405** of a power transistor such as power NMOS **102** illustrated in FIG. **1** or power NMOS **202** illustrated in FIG. **2**.

Within the cell area **405**, a capacitor including a plurality of sub capacitors **409** connected in parallel is arranged. The capacitor and the power NMOS may be monolithically integrated to form an integrated circuit as illustrated in any of FIGS. **1**, **2** and **3** for example. The sub capacitors **409** are spread evenly over the cell area **405**. The pattern of arrangement of the sub capacitors **409** illustrated in FIG. **4** is one example out of a vast variety of possibilities to evenly spread the sub capacitors **409** over the cell area **405**.

An alternative arrangement of the cell area **405** and the capacitor is illustrated in FIG. **5**. Here, the capacitor is arranged in a capacitor area **508** having a lateral distance d to a cell area **505** of the power transistor. The power transistor in the cell area **505** has a maximum turn off time τ . The turn off time τ and the lateral distance d satisfy approximately $d < 10^{-5} \text{ m}/\mu\text{s} \times \tau$. Thus, thermal coupling between the power transistor in the cell area **505** and the capacitor in the capacitor area **508** is achieved. In other words, when the temperature within the cell area **505** exceeds a certain threshold, thermal coupling between the cell area **505** and the capacitor area **508** leads to a decrease of the relative dielectric constant of the capacitor dielectric layer in the capacitor area **508**. As described with regard to the embodiment illustrated in FIG. **1**, this decrease in the relative dielectric constant is used to turn off the power transistor in the cell area **505**.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a variety of alternate and/or equivalent implementations may be substituted for the specific embodiments shown and described without departing from the scope of the present invention. This application is intended to cover any adaptations or variations of the specific embodiments discussed herein. Therefore, it is intended that this invention be limited only by the claims and the equivalents thereof.

What is claimed is:

1. An integrated circuit, comprising:

a power transistor with a power control terminal, a first power load terminal and a second power load terminal; an auxiliary transistor with an auxiliary control terminal, a first auxiliary load terminal and a second auxiliary load terminal, wherein the first auxiliary load terminal is electrically coupled to the power control terminal; and a capacitor with a first capacitor electrode, a second capacitor electrode and a capacitor dielectric layer including at least one of a ferroelectric material and a paraelectric material,

wherein the first capacitor electrode is electrically coupled to the auxiliary control terminal, and the second auxiliary load terminal, the second capacitor electrode and the second power load terminal are directly electrically connected.

2. The integrated circuit of claim **1**, wherein the power transistor has at least one of an on-state resistance of 10Ω or below and a specified blocking voltage capability of 300 V or more.

3. The integrated circuit of claim **1**, further comprising a semiconductor substrate including a monolithic integration of the power transistor and the capacitor.

4. The integrated circuit of claim **3**, wherein:

the power transistor includes a plurality of power transistor cells arranged in a cell area of the semiconductor substrate; and

the capacitor is arranged in the cell area.

5. The integrated circuit of claim **4**, wherein:

the capacitor includes a plurality of sub capacitors connected in parallel; and

9

the plurality of sub capacitors are spread evenly over the cell area.

6. The integrated circuit of claim 3, wherein:

the power transistor has a maximum turn off time τ and includes a plurality of power transistor cells arranged in a cell area of the semiconductor substrate;

the capacitor is arranged in a capacitor area having a lateral distance d to the cell area; and

the maximum turn off time τ and the lateral distance d satisfy $d < 10^{-5} \text{ m}/\mu\text{s} \times \tau$.

7. The integrated circuit of claim 1, further comprising:

a diode having an anode and a cathode; and wherein

the anode and the first auxiliary load terminal are electrically coupled to the power control terminal;

the cathode and the first capacitor electrode are electrically coupled to the auxiliary control terminal; and

the second capacitor electrode and the second auxiliary load terminal are electrically coupled to the second power load terminal.

8. The integrated circuit of claim 7, wherein:

the power transistor includes a power field effect transistor; the auxiliary transistor includes an auxiliary field effect transistor; and

a threshold voltage of the auxiliary field effect transistor is larger than a threshold voltage of the power field effect transistor.

9. The integrated circuit of claim 8, wherein a thickness of a gate dielectric of the auxiliary field effect transistor is larger than the thickness of a gate dielectric of the power field effect transistor.

10. The integrated circuit of claim 7, wherein a resistor having a resistance value of more than $10^3 \Omega$ is connected in parallel to the diode.

11. The integrated circuit of claim 1, further comprising:

a first diode having a first anode and a first cathode;

a second diode having a second anode and a second cathode; and wherein

the second cathode and the first auxiliary load terminal are electrically coupled to the power control terminal;

the second anode is electrically coupled to the first anode;

the first cathode and the first capacitor electrode are electrically coupled to the auxiliary control terminal; and

the second capacitor electrode and the second auxiliary load terminal are electrically coupled to the second power load terminal.

12. The integrated circuit of claim 11, wherein:

the power transistor includes a power field effect transistor;

10

the auxiliary transistor includes an auxiliary field effect transistor; and

a threshold voltage V_{th1} of the auxiliary field effect transistor is more than 50% higher than a threshold voltage V_{th2} of the power field effect transistor.

13. The integrated circuit of claim 12, wherein a gate dielectric of the power field effect transistor and a gate dielectric of the auxiliary field effect transistor are part of a same patterned dielectric layer.

14. The integrated circuit of claim 11, wherein a reverse breakdown voltage of the second diode is in a range of 5 V to 8 V.

15. The integrated circuit of claim 11, wherein a resistor having a resistance value of more than $10^3 \Omega$ is connected in parallel to at least one of the first diode, the second diode and the capacitor.

16. The integrated circuit of claim 3, wherein:

the auxiliary control terminal is a gate electrode; and

the gate electrode and one of the capacitor first electrode and the capacitor second electrode are part of a same patterned conductive layer.

17. The integrated circuit of claim 1, wherein the power transistor includes one of a metal oxide field effect transistor and an insulated gate bipolar transistor.

18. The integrated circuit of claim 1, wherein the auxiliary transistor includes a field effect transistor.

19. The integrated circuit of claim 1, wherein a temperature coefficient of the capacitor dielectric layer is negative.

20. The integrated circuit of claim 1, wherein the capacitor dielectric layer includes a ferroelectric material having a Curie point T_c of less than 300 K.

21. The integrated circuit of claim 1, wherein a relative dielectric constant $\epsilon_{(T1)}$ of the capacitor dielectric layer at a temperature $T1=400 \text{ K}$ and a relative dielectric constant $\epsilon_{(T2)}$ of the capacitor dielectric layer at the temperature $T2=475 \text{ K}$ satisfy $\epsilon_{(T2)} \leq 0.75 \times \epsilon_{(T1)}$.

22. The integrated circuit of claim 21, wherein:

the capacitor dielectric layer includes a paraelectric material; and

the paraelectric material includes at least one of BaTiO_3 , SrTiO_3 , $\text{Ba}_x\text{Sr}_{1-x}\text{TiO}_3$ and KTaO_3 .

23. The integrated circuit of claim 1, wherein:

the power transistor includes a plurality of power transistor cells arranged in a cell area of the semiconductor substrate; and

the auxiliary transistor is arranged in the cell area.

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